8. CONCLUSIONS AND RECOMMENDATIONS

The Groundwater Management Plan (GWMP) includes the review of available groundwater data and the development of a groundwater model for the preliminary west, central and east tunnel alignments as developed in the Fall Creek/White River Evaluation Study and Preliminary Design. The GWMP evaluates various scenarios using a computerized groundwater model to simulate potential impacts to groundwater reserves during future construction and long term operation of the tunnel. The GWMP is crucial for the protection of groundwater resources for the City of Indianapolis.

8.1 CONCLUSIONS

Based on information presented in this report, several conclusions were drawn for important components of the project. These conclusions are as follows:

- Available literature, boring logs and well information on the regional geology and hydrogeology were reviewed for the project. This provided background information on the topography and climate, soils, bedrock, and hydrogeology. However, limited bedrock geotechnical and aquifer/groundwater data were discovered within or near the proposed tunnel corridor.
- Average hydraulic conductivities were used in the model for the various aquifer layers because of the limited amount of available data.
- The hydraulic conductivity of the Silurian-Devonian carbonate aquifer beneath Indianapolis is highly variable and dependent upon the number and size of fractures that exist in the carbonate bedrock matrix. It is one of the most important aquifer parameters for the groundwater model because it governs the degree of communication between the deep carbonate aquifer where the tunnel will be constructed, and the shallower carbonate and alluvial aquifers where most water wells produce groundwater. The model relies on the data collected so far for the carbonate aquifer, such as the hydraulic conductivities determined from the Phase 1A geotechnical investigation packer tests and using standard assumptions by the tunneling industry for the calculation of tunnel infiltration rates using the Heuer Method. An extensive review of available data and literature from Indiana Department of Natural Resources

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(IDNR), Indiana Geological Survey (IGS), historical City records, and others has revealed limited relevant information concerning the hydraulic conductivity of the carbonate aquifer in the project area and at various depths along the tunnel alignment. Most existing wells have not been drilled or tested at such depths.

- The City's Riverside and Fall Creek bedrock wells were drilled in the early-to-mid 1900s to depths of 200-300 feet or more below the top of the carbonate rock. These wells are reported to have capacities between 200 gallons per minute (gpm) and 1,400 gpm. However, detailed boring logs and well installation reports are not available. Without detailed information about the screened depth intervals for each deep well that extracts groundwater, it is not possible to make reasonable estimates of the hydraulic conductivity at those locations.
- Hand-drawn sketches from 1974 for Riverside wells RS-2 and RS-9 show the drawdown inside the wells at a rate of 800 gpm each is below the top of the carbonate rock, but above the submersible pumps. At a rate of about 550 to 600 gpm for the wells, the sketches show almost half as much drawdown, which appears to be at least 20 to 25 feet above the pump bowls. Since the pump capacity of RS-2 is 650 gpm and the capacity of RS-9 is 700 gpm and assuming the pumps are currently set at the same depth as shown on the sketches, a decrease of 3 to 4 feet in groundwater levels caused by the tunnel should not adversely impact these wells.
- For alluvial well RS-B, data from 2002 show the pumping level inside the well at a rate of 950 gpm is just above the submersible pumps and top of well screen. The existing pump capacity for this well is 500 gpm. A drawdown of several feet caused by the tunnel should not adversely impact this well. Likewise, data from 2002 show that alluvial wells RS-C and RS-D were pumped tested at higher rates than the current pump capacities by approximately 200 gpm for RS-D and 600 gpm for RS-C. This should allow enough available drawdown to accommodate a lowering of the groundwater level by several feet during tunnel construction.
- Discrete hydrogeologic packer tests were performed for eight (8) deep borings that were drilled along the tunnel alignment during the Phase 1A Geotechnical

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Investigation. The borings extended up to 200 feet below the top of the carbonate rock, and the packer tests were performed at 10 to 20 foot intervals in the bedrock. The packer tests indicate consistent hydraulic conductivities ranging from approximately 4×10^{-7} centimeters per second (cm/sec) (0.001 feet per day (ft/day)) to approximately 4×10^{-3} cm/sec (11 ft/day) for the upper 50 feet of carbonate along the proposed tunnel alignment. This compares to published reports stating the average hydraulic conductivity for the upper carbonate in the Indianapolis area is around 13.4 ft/day (Cable et.al, 1971), and that the hydraulic conductivity for the upper carbonate throughout Indiana is highly variable ranging from 0.01 to 500 ft/day (Casey, 1992). For depths greater than 50 feet below the top of carbonate, the packer tests showed conductivities ranging from approximately 3×10^{-7} cm/sec (0.0009 ft/day) to 2×10^{-4} cm/sec (0.6 ft/day), but most of the values were in the 10^{-5} cm/sec to 10^{-6} cm/sec (0.003 to 0.03 ft/day) range. The published reports are generally consistent with the data collected during the Phase 1A Geotechnical Program indicating that the upper carbonate aquifer has a higher hydraulic conductivity than the lower carbonate aquifer.

- Boring B-10 is located near Riverside Wellfield bedrock wells RS-17, RS-22, and RS-29 which have reported capacities of between 600 and 700 gpm. The packer tests for B-10 showed hydraulic conductivities of 7.9×10^{-4} cm/sec (2.2 ft/day) in the shallow carbonate to 6.5×10^{-7} cm/sec (0.0018 ft/day) in deeper portions of the carbonate. These hydraulic conductivities do not appear to support a capacity of 600 to 700 gpm for a well. Assuming favorable well conditions with the maximum hydraulic conductivity of 2.2 ft/day for the entire thickness of the carbonate aquifer, assuming the bedrock well draws groundwater from an entire thickness of 250 feet, and assuming the pump is set very low in the well with an available drawdown of as much as 130 feet, the maximum capacity of a bedrock well is roughly estimated to be 350 gpm under confined aquifer conditions. It is unlikely that such favorable conditions exist, and the capacity of a well in a confined bedrock aquifer at this location would be lower than this and much less than the 600 to 700 gpm capacity that can currently be produced by the each of the wells. Based on this information, it appears that the deep bedrock wells are actually pumping

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mostly from the surficial alluvial aquifer through fractures in the upper portion of the surficial carbonate layer.

- It is possible that some of Indianapolis Water's bedrock wells may encounter deep fractures in the carbonate aquifer, and the hydraulic conductivity of the carbonate aquifer around those wells could be higher than indicated in published data and from results of the Phase 1A Geotechnical Program. However, to sustain pumping rates of 200 to 1400 gpm per well, the carbonate aquifer would need to be in good "communication" with the overlying alluvium and experience a high degree of recharge from the alluvial aquifer. The bedrock wells most likely extract the majority of their groundwater supply from the shallow carbonate aquifer by inducing groundwater to flow downward from the overlying surficial aquifer. It is concluded that the wells most likely produce very little groundwater from the deeper carbonate rock.
- Six (6) of the eight (8) Phase 1A borings were converted to piezometers. Each has a screen length of three (3) feet and is open to the carbonate aquifer in the zone above the proposed crown of the tunnel opening. As previously described in Section 5, the groundwater level measurements taken from these six (6) wells were used to calibrate the groundwater model.
- As discussed in Section 5 and shown in Figure 8.1, the trends in groundwater elevations for B-1 and B-3 follow a similar pattern as the trend in White River stream stage near the USGS gage at Raymond Street. This indicates that the White River and the shallow carbonate aquifer are hydraulically connected. The installation of future nested wells that monitor the deeper carbonate aquifer and shallow aquifers at the same time, along with monitoring the stage of the stream, will help determine the degree of hydraulic connection between the deep and shallow aquifers and streams.
- Also shown by Figure 8.1, the groundwater level recorded by B-10 fluctuates much more than at the other monitoring wells and more than the river stage. Piezometer B-10 is screened about 50 feet below the top of carbonate, and about 16 feet above the top of the proposed tunnel. B-10 is between approximately 800 to 2,000 feet away from six (6) Riverside wells (three (3) alluvial wells RS-A, RS-B, RS-C and three (3) bedrock wells RS-19, RS-17, RS-22). Assuming the borehole around B-10 is properly sealed from the

8. CONCLUSIONS AND RECOMMENDATIONS

surficial aquifer, the recorded fluctuation seems to indicate that at least the upper 50 feet of the carbonate aquifer at this location is affected by pumping from the City's wells, or some other local stress on the aquifer in this area.

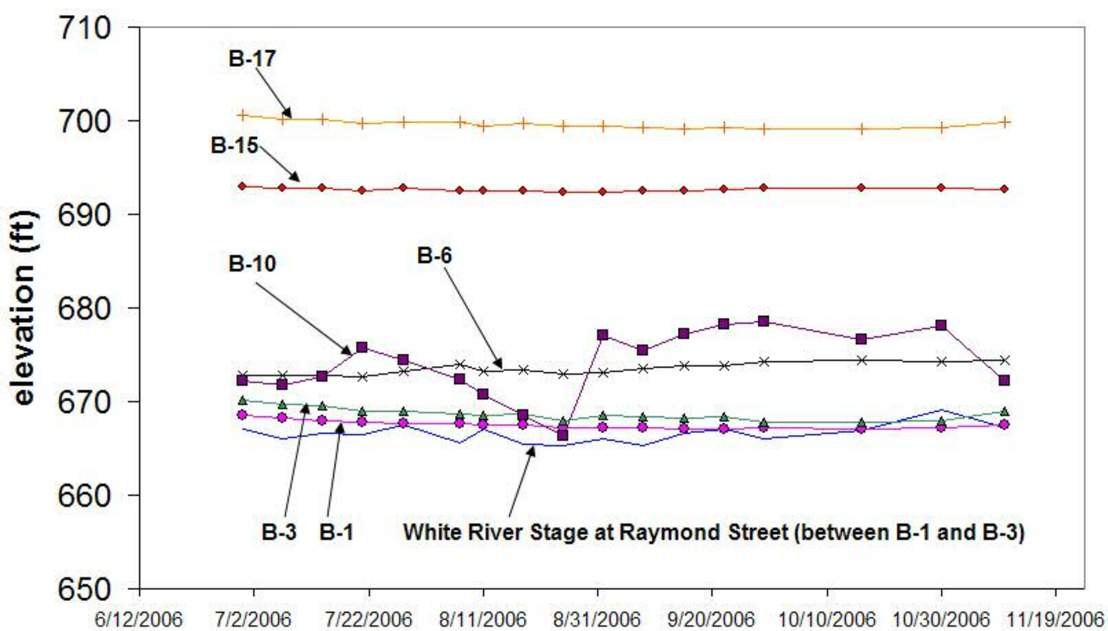

Figure 8.1 Fluctuations of Shallow Carbonate Groundwater Levels and White River Stage from June 2006 – November 2006

- This initial model evaluation indicates that the tunnel will cause a decrease in groundwater levels in the shallow aquifers by up to a maximum of 3 to 4 feet using high estimates of tunnel infiltration during construction. Existing wells nearest the tunnel alignment will be impacted by this amount. Near most wells, the model shows the tunnel will affect groundwater levels by about one (1) foot or less. A drawdown of several feet or less would only be a problem for a particular well if the current pumping level inside the well is just barely above a critical level such as the top of a well screen or the pump intake.
- As requested by project stakeholders, groundwater simulations of extreme conditions were performed with the model to evaluate what might happen if

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highly permeable conditions were encountered during construction. Under these highly unlikely extreme conditions, the tunnel would have the greatest impact on groundwater levels in the shallow aquifers if the following conditions were encountered during tunnel construction: 1) significant fractures extending from the shallow carbonate aquifer into the deep carbonate aquifer causing a high vertical hydraulic conductivity which hydraulically connects the aquifers, and 2) low to moderate horizontal hydraulic conductivity. For the immediate area along the tunnel alignment, these conditions would cause the greatest drawdown of groundwater levels in the shallow aquifers that existing wells extract groundwater. However, this extreme condition is not expected based on data evaluated during the Phase 1A Geotechnical Program.

- Under the highly unlikely extreme condition with a tunnel infiltration rate at nearly 10 times the expected infiltration rate, the model shows the tunnel would lower groundwater levels by up to 15 feet for the shallow aquifers where wells are believed to produce most of their water supply. However, this extreme condition is not expected based on data evaluated during the Phase 1A Geotechnical Program. If this situation were to occur, the tunnel would quickly flood and equilibrium would occur within one (1) week. In addition, a thorough geotechnical investigation and pre-excavation grouting program would mitigate the risk of such high infiltration rates from occurring.
- The East tunnel alignment impacts the most wells in the area by several feet, while the West tunnel alignment impacts the fewest wells. The East alignment does not follow beneath the White River or Fall Creek for as much of its length as the other alignments. Due to that difference in the East alignment, it appears the streams cannot provide as much recharge to offset the drawdown causing a greater impact to groundwater levels.

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8.2 RECOMMENDATIONS

This section provides a summary of the recommendations for future phases of work to help refine and confirm these initial estimates of the potential effect of the tunnel on the groundwater system in Indianapolis. Recommendations are as follows:

- A complete project risk register should be developed and continually updated and managed throughout design and construction of the tunnel system.
- Additional geotechnical and hydrogeological data should be collected and evaluated in future project phases prior to and during the design process. This will provide more data along the preliminary tunnel alignments, and will further confirm the quality and hydraulic conductivity of the carbonate bedrock at the proposed depth of the tunnel.
- Install, survey, and monitor three (3) nested monitoring wells (alluvial, shallow carbonate, deep carbonate), and a staff gage on the White River near the City's Riverside wellfield. Monitor groundwater and surface water elevations during times when the City wells are pumping and also at times when the wells are not being pumped. Obtain pumping flow rate data for the Riverside and White River wells during this time period.
- Near the Riverside and White River wellfields, install and survey a new test production well that is open only to the deep carbonate aquifer across the proposed zone of the tunnel. Attempt a short-term pumping test on this well to see if it produces any groundwater. If so, perform a longer term constant rate pumping test and monitor the groundwater elevations in the three (3) nested monitoring wells, and utilize this data to refine the estimates of horizontal and vertical hydraulic conductivity for the carbonate aquifer in this location. If the test production well does not produce any groundwater, this will confirm the limited hydraulic "communication" between the deep and shallow carbonate aquifer at this location.
- Visually inspect the core from piezometer B-10 to see if there are fractures or solution features that may help explain why groundwater levels in B-10 fluctuated much more than the other monitoring wells from June 2006 to November 2006. Obtain daily average pumping rates from Veolia Water for

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all nearby Riverside wells during this time period, if available. Compare the pumping rates from these wells to the groundwater levels recorded at B-10 to reveal hydrogeologic information about the carbonate aquifer at this location.

- Install, survey, and monitor two (2) additional staff gages in the White River near monitoring well B-1 and in Fall Creek near B-17. This will provide a measure of the fluctuation in surface water elevations compared to the groundwater elevations, which is important to the overall evaluation of the potential effects of the tunnel.
- Indianapolis Water and Veolia Water should obtain information for pumping levels inside each well, and confirmation of depths to the tops of screens or open holes for each bedrock well.
- After obtaining at least 18 months of detailed pumping data, river level data, and carbonate aquifer groundwater data, the groundwater model calibration should be reevaluated and updated.
- Continue to monitor groundwater levels in Phase 1A and future Phase 1B Geotechnical Program piezometers. This information will be invaluable to the overall GWMP and future project design, construction, and operational phases.
- Evaluate the potential for known contaminant plumes to migrate with the groundwater based on the modeled tunnel alternative scenarios. Additional information will need to be obtained for known contaminant plumes and localized hydrogeologic characteristics in the area of the plume during future project phases to assess this possibility.